The effect of indoor thermal and humidity condition on the oldest-old people's comfort and skin condition in winter

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The effect of indoor hygrothermal condition on the oldest-old people's hygrothermal comfort and skin condition in winter

Abstract:

In winter, dry indoor air is a common phenomenon which is considered to be the cause for dry skin. A field study was carried out to investigate the hygrothermal environment and its effect on the oldest-old residents' hygrothermal comfort and skin condition in a Scottish care home in winter. Eleven oldest-old residents participated voluntarily in the research. The room temperature and humidity were measured together with two skin parameters, the Transepidermal Water Loss (TEWL) and the Stratum Corneum (SC) hydration. The participants' personal hygrothermal comfort was studied by a questionnaire survey and short interviews.
The monitoring results show that the average relative humidity in the bedrooms was lower than 40%, the minimum RH level in winter recommended by the CIBSE Guide A. The SC hydration appeared to be a good indicator for humidity comfort, as it was significantly correlated with the room absolute humidity. The correlation makes it possible to predict the minimum humidity to prevent dry skin. The questionnaire results show the participants perceived a change in the room temperature but did not perceive the humidity changes. These research findings provide some evidence-based data that could help to develop the indoor environment standard for these special occupants group of the oldest-old people in care homes.
Keywords: oldest-old people, thermal comfort, humidity comfort, TEWL, SC hydration, care home

1. Introduction

With ongoing advances in medical technology, care support and living style, people are generally living longer than they have in previous decades. This however also presents a problem: ageing of the population, which is prominent in developed countries and some developing countries. In 2017, the share of the population aged 65 and over reached 19.5% while the share of the oldest old (aged 80 and over) population reached 5.5% in the EU, and these proportions are still increasing in every EU country [1]. Therefore, the research on the oldest-old population is important. Compared to other age groups, older people usually spend most of their time indoors. For the oldest-old population, more than 90% of their time is spent indoors, and this figure would be even higher in winter [2-4]. As most of their time is spent indoors, the quality of the indoor environment can greatly affect the oldest-old people's living and well-being.
However, there is lack of clearly guidance for design and services provision nor standards explicitly developed for this special group of occupants, whose physical and mental health conditions are very different from those subjects who participated in those studies that lead to the establishment of the indoor environmental standards that guide the design and manage the indoor hygrothermal conditions. The thermal comfort range recommended by popular HVAC design standards, such as the ASHRAE Standard 55 and CIBSE Guide A, was based on Fanger's study [5] which assumed no difference in thermal comfort between younger and older occupants. The assumption has been proved to be untenable by the fact that older adults generally prefer a warmer environment than the younger adults [6]. Therefore, the HVAC design standards should be developed and updated for the older occupants' comfort.
The oldest-old people's living environment is often not as good as they expected. Due to space heating and low moisture content in the outdoor air, the average RH indoors has been found to be around 30% in heated residential buildings in winter [7-9]. The dry indoor air situation is even worse in older people's living environment. Because of their physiological condition, older people normally prefer a 2°C warmer environment in winter compared to younger age groups [6]. This makes the room RH lower than the typical indoor spaces and makes the environment drier for the older occupants. Hence dry indoor air has become a common wellbeing problem in older people's living environments, especially in care homes and nursing institutions for the elderly [10].
Dry indoor air not only provides discomfort feelings but raises the prevalence of xerosis (dry skin). Xerosis is

one of the most frequently suffered health issues among older people. It can result in a series of skin symptoms, such as itchiness, pruritus and cracks [10]. Its prevalence of older people is 29.5% to 45.3%, mostly affecting the oldest-old people, among other age groups [10, 11]. Although the exact aetiology of xerosis on older people is not entirely understood, air humidity has been considered as an important factor in the condition's development [12]. Several studies reported that the prevalence of xerosis on older people in care homes was higher during the heating seasons and was directly associated with the dry indoor air due to space heating [13] [14]

However, to our knowledge, limited studies have been performed on the effect of dry indoor air on the skin. A climatic chamber study proposes a minimum RH of 30% should be maintained to avoid dry skin on older adults [15]. This argument is based on comparing the data in three different RH settings (10%, 30% and 50%) in 180 minutes of exposure. A setting of 45% minimum RH is recommended to prevent dry skin [10], but the authors did not present the data to support their statement. Thus, there is a need to investigate the impact of dry indoor air on skin condition, especially on the oldest-old people. The aim of this study is to investigate and quantify the indoor hygrothermal condition in a care home and explore its impact on the oldest-old people's skin condition in the living environment. Through a specific survey procedure, both environmental objective data and personal subjective data are collected and analyzed. This procedure allows the data to be collected in a normal live setting that minimizes the possibility of uneasiness of the occupants taking part in the survey. Consequently, the results drawn from the data should reflect the true situations in care homes and the associated occupants' responses.

2. Methodology

2.1 The care home

The care home is located in the city centre of Edinburgh, Scotland, UK, offering full-time catering and residence for older females only. It is a two-story centrally heated building consists of a Georgian house to the South (including a dining room, a glass conservatory, living rooms, offices and maintenance rooms) and a new extension to the North for 23 en-suite bedrooms over two floors. Each floor was connected by a lift and a major stair in the Georgian house and a minor stair in the north extension.

The living rooms, conservatory, dining room (where the occupants spent most of their time in the care home) and the participants' bedrooms were selected for data collection. Each room is heated by wall-mounted radiators with thermostatic controlling the room temperature. No ventilation devices are installed in the rooms, excluding a delay-extract fan in the en-suite bathrooms to prevent the smell and moisture going into the bedroom when it is in use.

2.2 Research participants

Eleven participants voluntarily participated in this research through an ethically approved recruitment process. The participants are all white females, ageing from 83 to 94 (mean ± STD: 88.81±3.97) years old with no skin disease or cognitive dysfunction. Due to their very old age, they have various degrees of difficulty in hearing, reading and writing.

In the recruitment, a simple information sheet that introduces the research background, aim and objectives, was provided to all the residents in the care home. Eight of the participants signed and returned the consent form by themselves. The remaining participants, who have difficulty in signing their name, orally accepted the consent form and authorized their family to sign and return the consent forms.

2.3 Skin condition

To assess the skin condition, two skin parameters were selected and measured on the distal right volar forearm of the participants - the TEWL and the SC (Stratum Corneum) hydration. TEWL is defined as the flux density of water diffusing from the dermis and epidermis through the stratum corneum to the skin surface [16]. It shows the capacity of the skin's barrier function, which is clinically relevant to skin diseases [17-19]. TEWL is universally used for skin assessment as the measurement is straightforward, non-invasive and economical [17, 18]. TEWL has been proved to be affected by the ambient air temperature, humidity and velocity [18], and varies on different skin area [20]. According to a number of studies on research subjects ageing from 18-64 years old, the average TEWL on the distal right volar forearm is 7.3-11.8 $g \cdot m^{-2} \cdot h^{-1}$ [20]. An increase in the TEWL indicates an impaired skin barrier function.

Another parameter to assess the skin condition is the SC hydration. SC hydration is the moisture content in the outermost layer of skin. It is indirectly measured through a combined variable of skin's electrical properties, which are relevant to the moisture content in the horny layer [19]. When the skin is submitted to an alternating current, the total impedance of the skin can present the skin hydration status [19]. The SC hydration is presented in arbitrary units (a.u.). Values below 35 a.u. denote for very dry skin, between 35-50 a.u. denote for dry skin and over 50 a.u denote for a sufficiently moisturized condition [21].

2.4 The questionnaire

To understand the participants' responses to the environment, a questionnaire survey was designed and carried out in parallel with the skin measurements. The questionnaire consisted of the questions on both thermal and humidity comfort. The questions on thermal comfort were based on the BS EN ISO10551-2002 [22] and ASHRAE Standard 55-2017 [23] and the questions on humidity comfort were based on relevant studies [24]. Due to the facts found in an early trial that the time to concentrate on a task for the oldest-old was short, the standard questionnaire (Table 2) were modified using a graphic based IOS Application on a tablet with an individual interview.

The questions consist of subjective hygrothermal comfort in perception, satisfaction and preference (Table 1). To assist comprehension, carefully selected images accompanied most questions: a "snowflake" presenting "cold" and a "burning sun" presenting "hot" in the thermal perception question; a "cactus in the desert" presenting "very dry" and several "water drops" presenting "very moist" in the humidity perception question; a "smiling face" presenting "comfortable" and an "angry face" presenting "extremely uncomfortable" in the thermal and humidity preference questions. A validation work was conducted to confirm that the images used were correctly associated with the hygrothermal conditions they are designed to represent.

Each questionnaire was completed for one participant at one location in one visit. All questions and answers were given orally as most of the participants had difficulty in hearing, reading and writing. In addition, the questionnaire survey was associated with a short interview afterwards. The interview allowed the participants to comment on the environment in the living areas and/or in their bedrooms. Each participant could provide more than one comment.

Scale points	Thermal perception	Thermal satisfaction	Thermal preference	Humidity perception	Humidity satisfaction	Humidity preference
-3	cold	very uncomfortable	much cooler	very dry	very uncomfortable	much dryer
-2	cool	uncomfortable	cooler	dry	uncomfortable	dryer
-1	slightly cool	slightly uncomfortable	slightly cooler	slightly dry	slightly uncomfortable	slightly dryer
0	neutral	comfortable	without change	neutral	comfortable	without change
1	slightly warm		slightly warmer	slightly moist		slightly moister
2	warm		warmer	moist		moister

3	hot	much warmer	humid	much moister

Table 1 Scale of subjective judgments

2.5 Measurements and procedure

The measurements were carried out in four periods in order to cover a range of humidity levels that are likely to be found in a typical room and an intervention measure can be implemented. In the first period from January 25th to February 4th, no environmental interventions were applied to the measured bedrooms. In the second period from February 5th to February 12th, a simple intervention was applied: all measured bedrooms were humidified by Prem-I-Air Sonico, a simple domestic ultrasonic air humidifier to the target humidification setpoint of 40% RH. In the third period from February 13th to February 15th, the intervention was stopped in all measured bedrooms. In the fourth period from February 16th to February 21st, the intervention was applied again in all the rooms and the target humidification was set to 50% RH. Because the living areas were also occupied by the occupants who did not participate in the research, the intervention measure was not applied in the living rooms, dining room and conservatory during the whole research period.
The room temperature and RH were measured by the Tinytag Ultra 2 TUG-4500 Internal Temperature/Relative Humidity Data Logger. Each logger was installed at approximately 1.5m to 2.0m height in each of the measured rooms and set to log data every 10 minutes. The room absolute humidity (AH) was calculated by the measured room temperature and RH. The TEWL and SC hydration were measured by the Courage-Khazaka MPA-5 Central Multi-probe Unit with the Tewameter TM 300 (measuring TEWL) and the Corneometer CM 825 (measuring SC hydration). The skin measurements are non-invasive and did not cause any damage or discomfort to the skin and measurement takes less than 2 minutes normally and hence minimize the disruption to the subjects.

Device	Measurement range	Measurement resolution	Measurement accuracy	Measurement uncertainty
Tinytag Ultra 2 TUG-4500	-25 ~ 85°C	0.01°C	0.4°C	-
	0 ~ 95 % RH	<0.3% RH	±3% RH	-
Tewameter TM 300	0 ~ 70 g/h/m²	0.1 g/h/m²	-	±0.5 g/h/m²
Corneometer CM 825	-	0.1 a.u.	-	±3%

Table 2 Specifications of the measurement devices

Two visits were paid in each period to each participant for the skin measurements and questionnaire survey. In each visit, the skin measurements and questionnaire survey were carried out by two researchers respectively together with the assistance of the care home. As the skin measurements would be affected by the room temperature, RH and air velocity [19], the environmental parameters were checked before the skin measurements. All the skin measurements were carried out under the condition of air velocity less than 0.05m/s when the participant was sitting at ease (metabolic rate 60-70W/m^2 [23]) and was in normal winter ensemble with light outdoor clothing (clothing insulation 1.35clo to 1.55clo [23]).

2.6 Statistical analysis

Data for comparing the intervened and non-intervened room condition were analyzed by the paired T-test. Results of the objective and subjective data were analyzed by repeated measure analysis of variance (ANOVA) without replication through the IBM Statistical Package for the Social Sciences (SPSS) Statistics 22 software. The significance level was set to be 0.05 (P<0.05). Data were expressed as means ± SD.

3. Results

3.1 Environment measurements

Figure 1 shows the indoor and outdoor hourly temperature and RH during the research period. The outdoor average temperature and RH were 4.84°C and 84.67%, while the indoor average temperature and RH were 22.91°C and 35.1%. The indoor temperature and RH fluctuations were much smaller than that outdoors, which shows a good performance of thermal and moisture insulation of the building.

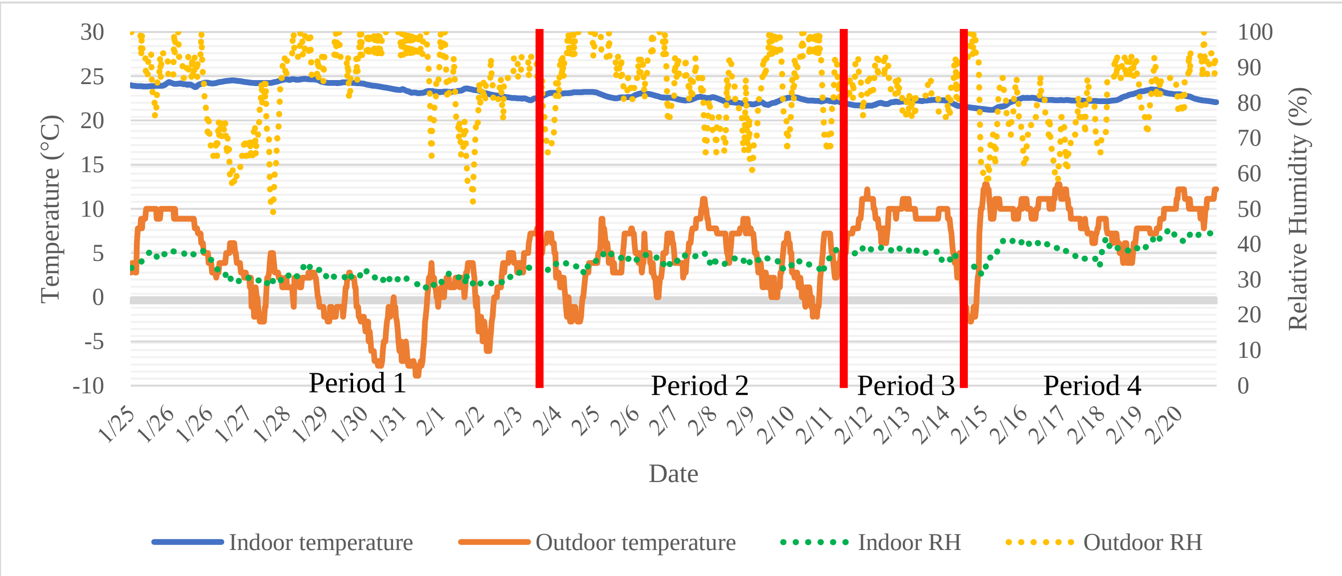

Figure 1 Indoor and outdoor hourly temperature and relative humidity

Figure 2 shows the hourly temperature and RH in the bedrooms and living areas during the research periods. The average temperature in the bedrooms and the living areas were stably kept around 23.93°C and 21.53°C respectively. The temperature in the bedrooms was normally about 2°C higher than that in the living areas. In the first period when the humidity was not intervened, the average RH in the bedrooms was 30.8%, which did not meet the minimum RH level recommended by the CIBSE standard [25]. In the second period when the target humidification was set to 40% in the bedrooms, the average room RH increased to 34.4%. In the third period when the humidification was stopped, the average room RH continuously increased to 35.6%, which did not drop as expected. In the final period when the humidification was applied again in the bedrooms and the target humidification was set to 50% RH, the average room RH increased to 39.4%. As for the humidity in the living areas, the average RH in the conservatory was 46.5%, which was much higher than that in the dining room and living room where the average RH were 38.2% and 34.3% respectively. The higher average RH in the conservatory was very likely due to the air leakage through the window panels, which is common in glazed conservatories. In summary, humidity in the bedrooms was intervened by the humidifier but did not reach the target setpoint. Humidity in the living areas was normally about 5-10% higher than that in the bedrooms when they were not humidified.

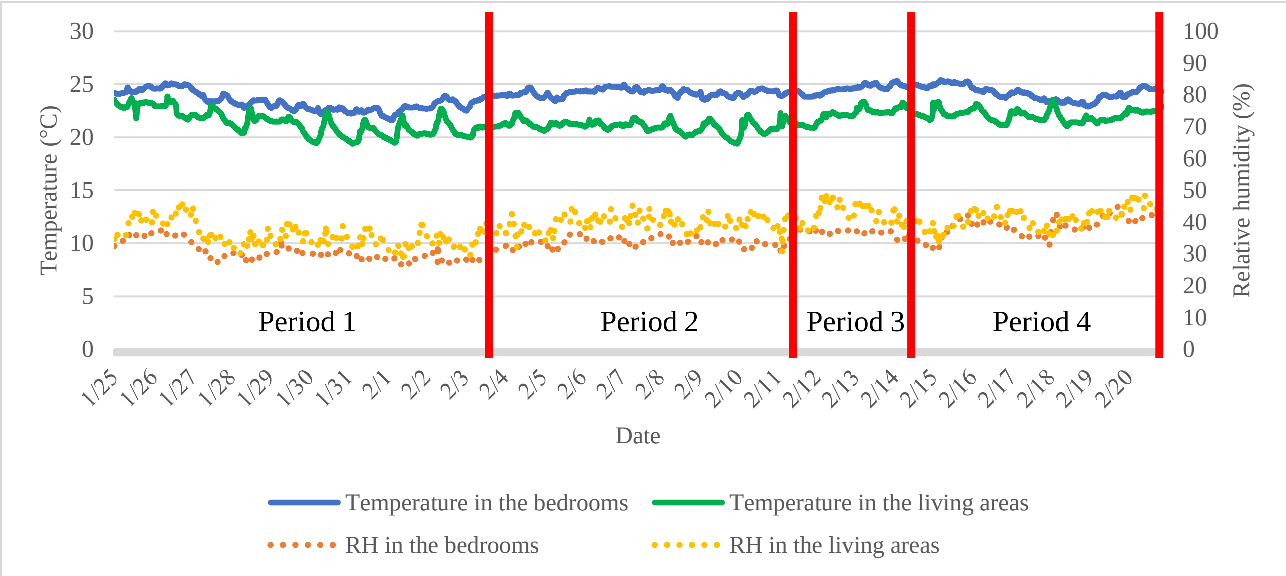

Figure 2 Hourly temperature and RH in the bedrooms and the living areas

Figure 3 shows the temperature distribution in and outside the thermal comfort range for average occupants in winter (17-23°C [25]) in the measured rooms. In nine out of eleven bedrooms, the temperature was higher than the upper level of the thermal comfort range most of the time, which is in line with the fact that elderly people prefer a warmer indoor environment [2]. It is worth mentioning that the care home cleaning staffs operated regular cleaning in each bedroom in mornings. During the process, all windows and doors in the bedroom were kept open for around 15-20 minutes for ventilation, which brings down the average temperature. Besides, the temperature in the living areas was higher than the upper level of the thermal comfort range most of the time, excluding in the conservatory. In the conservatory, the average temperature was 18.20°C, which is approximately 5°C lower than that in the dining room and the living room. Such a low room temperature was due to the high U-value of the glass structure in the conservatory and the high air infiltration through the glazing panels.

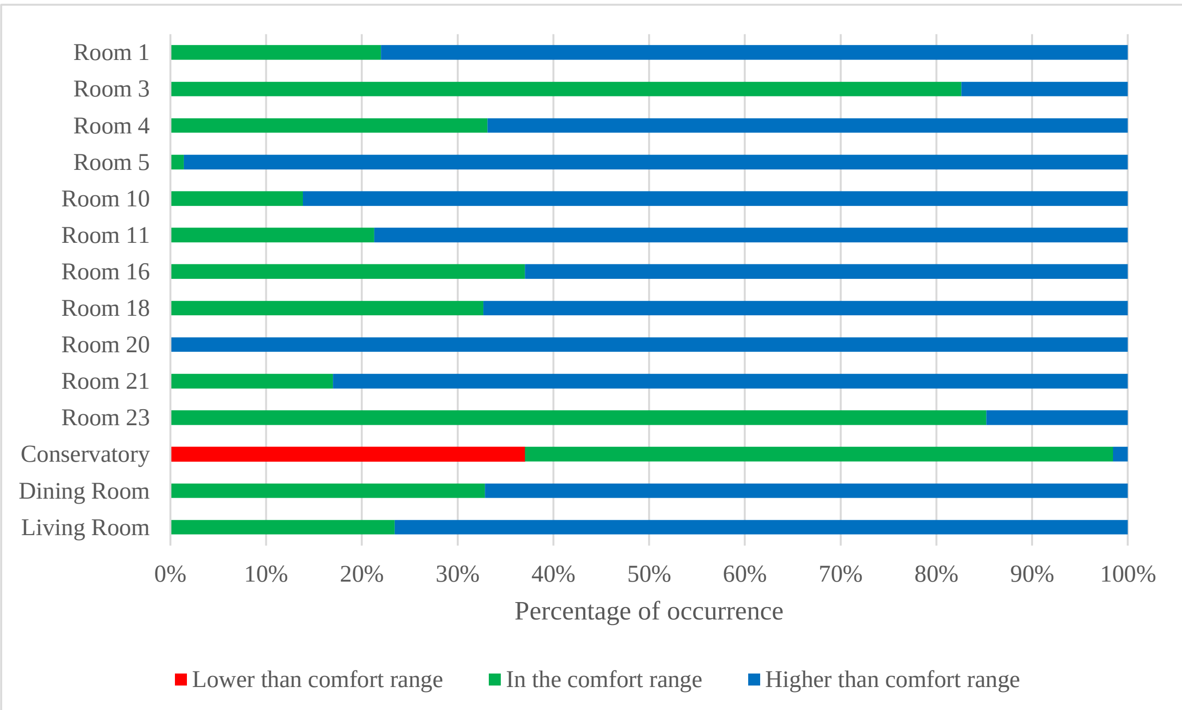

Figure 3 Percentage of occurrence in and out of the thermal comfort range in each measured room (comfort range for average occupants: 17-23°C)

Figure 4 shows the humidity distribution in and outside of the recommended humidity comfort range (40-70% RH [25]) in all measured rooms. In the first period when no humidity intervention was applied and all the rooms were measured under their original conditions, the humidity in all the measured bedrooms was lower than the comfort range for the majority of the period. In the second period, when humidification was set to 40% RH, the humidity increased in four out of eleven bedrooms. Humidity in Room 10 and 23 were within the comfort range for more than half of the period. In the remaining nine rooms, the humidity increased by various degrees, but, generally, the percentage of occurrence of the humidity reaching the comfort range did not change significantly. In the third period when the humidity intervention stopped, the humidity in seven rooms did not drop as expected but remained more or less unchanged. This could be because ventilation in these bedrooms was not enough to remove the moisture introduced in the previous period. Moreover, in the remaining four bedrooms, the percentage of occurrence in the comfort range increased instead of decreasing or remaining unchanged. The humidity distribution in the living areas did not change significantly in the dining room and living rooms. However, humidity in the conservatory was higher than 40% since the second period but did not exceed 70% RH, the upper band of the comfort range.

Figure 4 Percentage of occurrence in and out of the humidity comfort range in each measured room in each period (comfort range for average occupants: 40-70% RH)

3.1 Skin measurements

Most of the skin measurements were carried out in the living rooms and the conservatory, in order to minimize the disruption to the participants' normal routine.

The TEWL was not significantly correlated with the room temperature ($P>0.05$) but significantly correlated with the room RH ($r=0.32$, $P<0.01$). A significant correlation was also found between the TEWL and the room AH ($r=0.28$, $P<0.01$, Figure 5), a variable that was derived from the room temperature and RH.

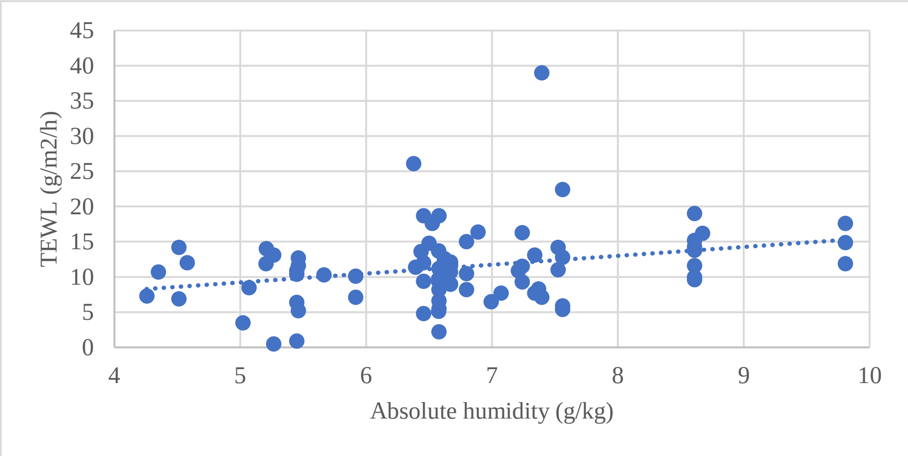

Figure 5 TEWL as a function of the room AH at the moment of the skin measurement

For the SC hydration, neither room temperature nor RH was found to be significantly correlated with the SC hydration (P>0.05). A significant correlation was found between the SC hydration and the room AH (r=0.32, P<0.01, Figure 6). As the correlation is positive, higher room humidity contributed to a more moisturized skin condition. According to the minimum SC hydration of the well-moisturized skin condition (50 a.u. [21]), a minimum level of 41% RH could avoid dry skin which can be predicted if the room temperature is maintained at 21°C. In addition, 35.44% of the measured SC hydration levels were less than 50 a.u., showing the skin was not sufficiently-hydrated. Among them, 5.06% of the measured SC hydration values were less than 35 a.u., showing the skin was very dry.

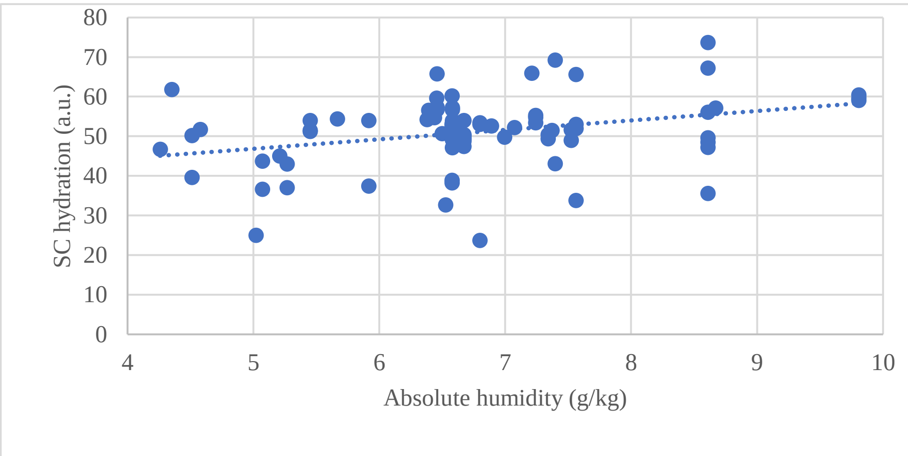

Figure 6 SC hydration as a function of the room AH at the moment of the skin measurement

In addition to the indoor hygrothermal condition, the TEWL and SC hydration were found to be correlated with the outdoor environment. Significant correlations were found between the outdoor temperature and the TEWL (r=0.22, P<0.05), and between the outdoor temperature and the SC hydration (r=0.32, P<0.01), showing the outdoor temperature and humidity also affected the skin condition.

3.2 Subjective responses

We proposed to use the designed six-question questionnaire to investigate the participants' subjective hygrothermal comfort in perception, satisfaction and preference. However, at the beginning of our first visit, the first two participants expressed huge impatience to the questionnaire and complained the six questions were too long. Additionally, because the participants have different degrees of difficulty in hearing, reading and writing, each participant spent 15-20 minutes answering the questions, which was time-consuming. Therefore, after these two participants, we used a simplified questionnaire to ask their temperature and humidity perception and a short interview to acquire their comments and complaints to the indoor environment instead of the full six-question questionnaire.

Figure 7 shows the thermal perception as a function of the air temperature at the moment of answering the questionnaire. The participants answered “neither cold nor hot” in 51.14% of the answers, which shows most of them felt thermally neutral. Their thermal perception was significantly correlated with room temperature ($r=0.26$, $P<0.01$). As the correlation was positive, the participants’ thermal perception increased with the room temperature, which shows the participants could sense the temperature change and express their perception. According to the graph, a neutral temperature of 22.78°C can be predicted.

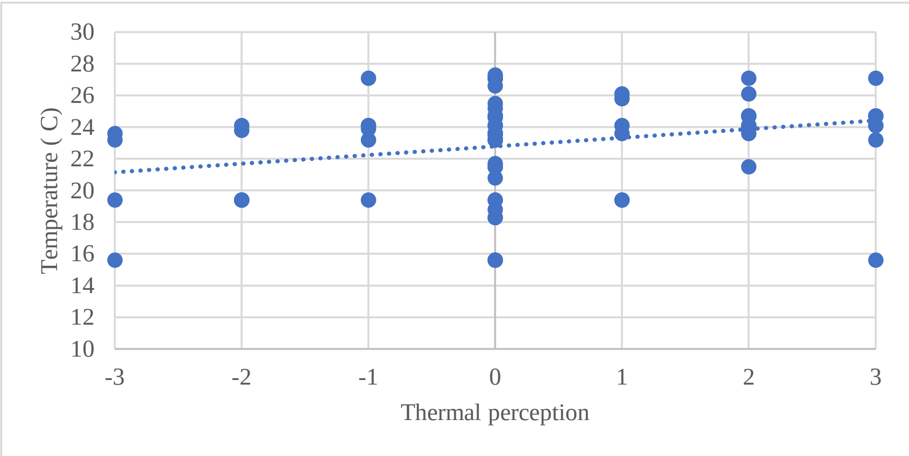

Figure 7 Thermal perception as a function of the air temperature at the moment of answering the questionnaire

Figure 8 shows the humidity perception as a function of the room RH at the moment of answering the questionnaire. The humidity perception was significantly negatively correlated with room RH ($r=-0.29$, $P<0.01$). The negative correlation means the participants felt even dryer when room humidity increased. This may be because the participants were not able to sense the humidity change and/or the room RH was not the major factor affecting their humidity sensation. In addition, no significant correlation was found between humidity perception and room AH ($P>0.05$).

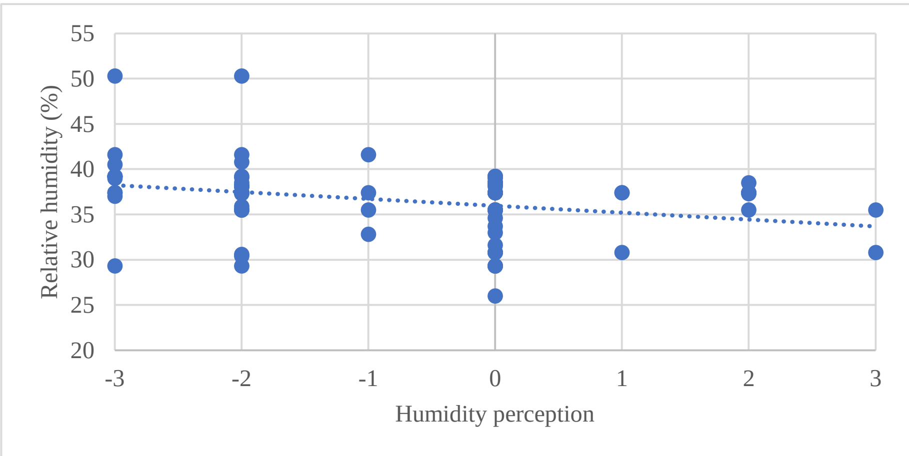

Figure 8 Humidity perception as a function of the room RH at the moment of answering the questionnaire

87 comments or complaints on the indoor environment were obtained from the 73 interviews after the

questionnaire survey (Figure 9). In 26 interviews, the participants unequivocally expressed "comfortable" with the environment. However, because all the interviews were carried out under the supervision of the care home staff, some participants may not wish to complain in front of the care home staff and always expressed "comfortable" in the interview. In addition to this, in six interviews, the participants expressed they did not like to complain, which may also be because of the presence of the care home staff. Moreover, in ten interviews, the participants unequivocally expressed they were unable to sense or did not notice the humidity in the room.

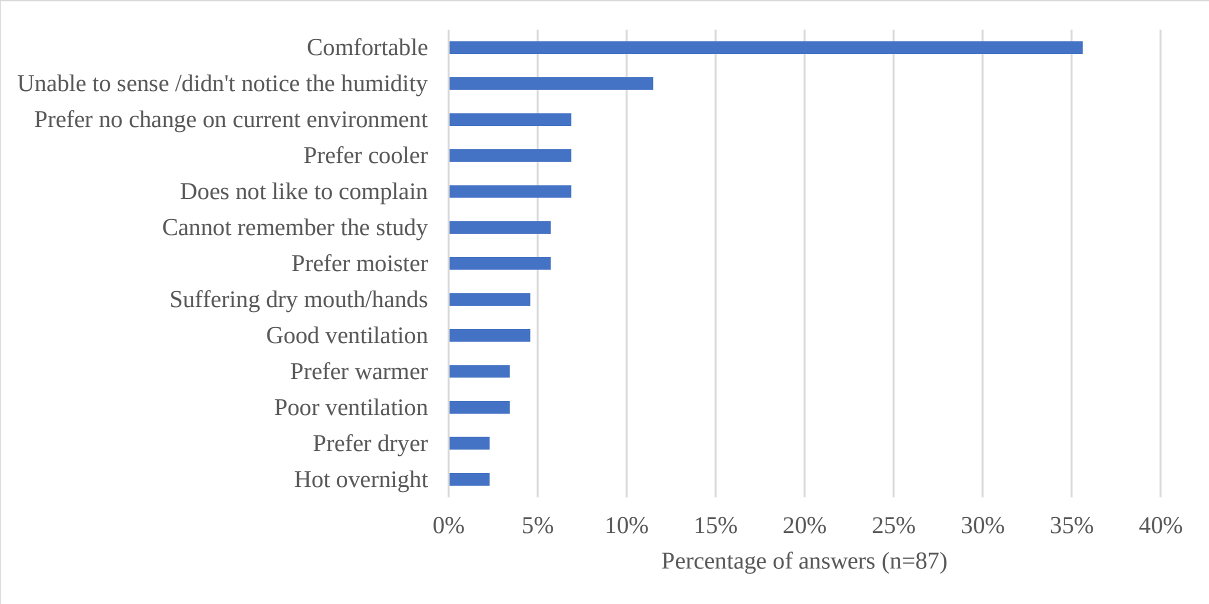

Figure 9 Comments and complaints on the indoor environment

4. Discussion

4.1 Room temperature and humidity

The temperature in the bedrooms was higher than the thermal comfort range, but most of the older participants were satisfied with the temperature. The result shows that older people prefer a warmer environment and the thermal comfort range recommended by HVAC design standards is not warm enough for older occupants. This phenomenon has been reported and discussed by van Hoof [2], who pointed out weakness of the thermal comfort range recommended by popular HVAC design standards, such as ASHRAE Standard 55 and CIBSE Guide A: their recommended thermal comfort range was based on studies by Fanger [5], who concluded no difference in thermal preference was assumed between younger and older people through climate chamber studies involving approximately 1300 college-age students and much smaller sample size of 128 older subjects, but studies found the thermal comfort range is not warm enough for older adults and older adults generally prefer a warmer environment [6]. Therefore, the current thermal comfort range is not warm enough for older occupants and a warmer environment should be provided in their living environment to fit their preference.
The humidity in the bedrooms was constantly lower than the recommended standard without any intervention on humidity and should be increased at least closer to the lower end of the recommended range. The average RH in the bedrooms in this period was 30.8%, which was much lower than 40% RH, the recommended minimum RH in winter [25]. Unlike the temperature, indoor humidity is mainly affected by the occupant's activities such as washing and others, making it possible for the occupants to adjust the indoor humidity by adapting behaviours, for example drying a wet towel or spraying water, in normal circumstance. However, due to their very old age and safety considerations, the oldest-old people are usually not able to actively adjust but passively bear the environment. To help them ease the problem, using a humidifier could be a simple and effective solution. As shown in Figure 4, the percentage of time in the humidity comfort range obviously improved when the humidifiers were used. However, the use of humidifiers is not common in winter. One

research on the frequency of humidifier usage in South Korea shows that only 37.2% of the interviewed people used humidifier from December to February, and this figure dropped to 3.2% in the age group over 60 years old [26]. Therefore, promoting the using of humidifiers can effectively improve the humidity comfort in winter heated care homes, especially in the bedrooms.

Another issue in the bedrooms of the care home is poor ventilation. In this research, room humidity could be seen as an indicator of ventilation efficiency. In the third period when the humidification stopped, the RH in most of the bedrooms did not decrease as it was expected to (Figure 4), which means the ventilation in the bedrooms was not sufficient to exhaust the moisture generated in the previous period. If the moisture generated cannot be exhausted and the humidification continues without control, the accumulated moisture could result in high room humidity and increase the emission of VOCs (volatile organic compounds). Researches show that increasing RH could markedly contribute to the emission of VOCs from building materials [27, 28] and the VOCs could create health problems[29]. Thus, the humidification process in residential buildings should accompany with sufficient ventilation.

4.2 Skin condition measurements

The measured TEWL was significantly positively correlated with the room RH ($r=0.32$, $P<0.01$) and the room AH ($r=0.28$, $P<0.01$) respectively, which means higher room humidity leads to a higher TEWL. However, as higher TEWL indicates a poorer skin barrier function, this result is opposite to a validated conclusion that higher skin exposed humidity contributes to a better skin condition and could ease the dry skin [10, 12, 19]. One possible explanation to the result is both the skin's TEWL and the measurement accuracy were affected when the room environmental condition changed. The TEWL is recommended to be measured at a constant room condition with temperature 18-21°C and RH of 40-60% [18]. However, the requirement was not met in this study and the TEWL measurements were carried out at different room temperature and RH. In addition to this, the measurement device is likely to be affected by the environment. The measurement device Tewameter TM 300 uses an open-chamber method whose measurement sensors are exposed to the ambient environment, making it very likely to be affected by the ambient temperature and humidity change and air movement. One study that was carried out in an inconstant environment also reports an increase of TEWL when skin exposed RH increased from 10% to 50% [15]. Therefore, measuring the TEWL in an inconstant environment is infeasible and the measured TEWL in this study is not suitable for reflecting the effect of indoor humidity on skin condition.

For the measured SC hydration, it was not significantly correlated with either the room temperature or the RH ($P>0.05$). This result is different from the climatic chamber studies that reported the SC hydration shows a steady increase in function of the temperature above 22°C at constant humidity [30] and follows a linear relation ($r=0.98$) in function of an increase in RH from 37% to 87% at constant temperature of 18-22°C [31]. However, a significant correlation was found between the SC hydration and AH ($r=0.32$, $P<0.01$). This result shows the room humidity affected the skin hydration more than the room temperature did and, more importantly, this effect is measurable at varied temperature and humidity levels in a real living environment. The stratum corneum is the major component of the epidermis which is directly exposed to the ambient environment. Low humidity in the ambient environment may result in a decrease of the hydration state in the stratum corneum, which may attribute to changes in the keratinization process. Keratinization process is a balance between keratinocytes' flattening after they migrate from the basal layer to the stratum corneum and desquamating when the cells die off. Any imbalance in the keratinization process will result in flaking and dry skin [10]. By measuring the SC hydration at different room humidity levels, a numerical relationship between the room hygrothermal condition and skin condition can be established and the minimum humidity level that could prevent dry skin can be predicted. In this research, a minimum level of 40.62% that could make the skin in a well-hydrated condition can be predicted if the room temperature is maintained at 21°C. This method is applicative to not only the oldest-old people but also all other age groups, especially those who are not able to participate in climatic chamber studies, to solve the dry skin issue in winter.

4.3 The questionnaire survey

We also noticed that the seven-scale and the questions in the standard CIBSE questionnaire were not appropriate to be used for the oldest-old the special subjects in this study. Firstly, the seven-scale provided too many options as almost all of the subjects found it was difficult to discern the difference between two neighbouring scales. Hence a simpler way should be applied. The scale of five, or even three could be enough for this group of subjects. Secondly, the questions were too long for the oldest-old participants, who had difficulty in reading, hearing and writing, and therefore trying to understand and answer may cause them stress. To solve this problem, the questions were displayed by a tablet as well as asked verbally and a short interview was arranged with each subject to acquire their subjective responses, comments and complaints. By doing this, the participants were more willing to communicate with us and provided more information in a pleasant way. Thirdly, the participants often gave irrelevant answers to our questions. For example, when we were answering "how do you feel about the temperature at this moment?' and presented the seven-point answers on the scale from "cold" to "hot", most of them would answer "I feel comfortable" or "I am fine". To solve this problem, some images, for example using smiling and angry faces to present satisfaction and dissatisfaction, were selected to help them give the relevant answer and make the communication efficient. Finally, the presence of the care home staff may interfere with the results of the questionnaire survey. Due to the ethical and safety considerations, this study was carried out with the assistance and under the supervision of the care home staff. Sometimes the care home staff would help us to ask the questions to the participants. However, some participants seemed unwilling to complain and more selective to the "comfortable" and "neutral" answers in front of the care home staffs, although they had understood the questionnaire survey was the part of academic research and their answers would not give any negative impact on the care home or themselves. Because of this, we communicated with some participants in private, but they all denied that they refused to tell true feelings because of the presence of the care home staffs. These findings could help and give innovations to the research on the oldest-old people.

5. Conclusion

Overall, the subjective assessment using questionnaire surveys shows that the participants were generally satisfied with the hygrothermal condition in the care home. The objective measurement shows that the humidity in the bedrooms was low and did not meet the HVAC design criteria. By using a humidifier, the room humidity could significantly improve the room humidity, but sufficient ventilation should be provided to prevent over humidification and the extra VOCs emitted due to high humidity.

The TEWL is not suitable for measuring the effect of indoor humidity on the skin condition in the real living environment due to the inconstant measurement environment and the measurement error of the measurement method and device used in this study. The SC hydration showed a significant correlation with the room AH. Based on the correlation, a minimum humidity of 41% RH could avoid dry skin which can be predicted if the room temperature is maintained at 21°C. By measuring the SC hydration in various humidity levels, the relationship between indoor environment and skin hydration can be established, making it possible to predict the minimum humidity level that could avoid dry skin.

Besides, the traditional seven scales in the hygrothermal comfort questionnaire were too many when applying to the oldest-old people, as the oldest-old people have difficulty to discern the subtle difference between any two neighbouring scales. As they also have difficulty in reading and writing, the questionnaire survey should be conducted by one to one communication, which demands extra time, patience and cooperation from the participants. To address this issue, the future questionnaire surveys on the older people should have a revised short version and be associated with a short interview to allow the interviewees complaining or commenting on the environment instead of just answering questions. In addition, using appropriate graphics could help the oldest-old people understand the questions. Moreover, as the research was carried out under the supervision of the care home staffs due to ethical and safety considerations, the presence of the staff may have affected the participants' feedback. Measures should be considered to avoid the interference on the participants' answers from the irrelevant personnel in future studies.

Finally, the study was the first stage of the attempt to collect evidence-based data that would show a feasible way to develop an appropriate hygrothermal range for older occupants' comfort and skin health. The study should be continued to cover more subjects and gather more data to build better confidence, and eventually lead to the establishment of specific standards of this very special group of occupants, the oldest-old people. By doing so it can guide the design and service providers to offer better comfort and wellbeing for the final stage of their lives in care homes.

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